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## ABSTRACT

According to Piaget, young children have a profoundly different conception of distance than do adults. In fact, Piaget argues that young children do not have a conception of distance since they do not conceive of distance as being composed of fixed units of space. In contrast, results of a series of studies indicate that in tasks requiring distance judgments of large-scale and small-scale paths, judgments of paths with and without interposed points, and judgments of visible and unseen paths, young children's concepts and judgments of space are determined to a significant degree by a fundamentally correct conception of distance. As Piaget has argued, a conception of distance is basic for an understanding of space; such a conception occupies a fundamental position in the child's thinking and reasoning about space. In contrast to Piagetian theory, findings show that the acquisition of a concept of distance is evident quite early in development. Reproductions of 11 slides used during the presentation are appended. (RH)

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Spatial Knowledge Versus Perceptual Biases

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## Spatial Knowledge Versus Perceptual Biases

This symposium examines spatial problem solving and its implications for other aspects of cognitive development. We began the that we will talk about today with an interest in a particular sort of spatial problem solving, namely children's searching. Studying children's search has furthered our understanding of many aspects of cognitive development. In one guise or another, search tasks have allowed investigators to compare the problem solving strategies of infants and young children, to study children's spatial representations, and to chart the emergence of relatively sophisticated forms of cognition such as logical inference and planning. Studying children's search led us to be interested in another aspect of cognition, namely children's conception of distance. We began this research because we were struck by the following contradiction. On the one hand, some of our studies on search led us to believe that preschool children possess rich and accurate conceptions of distance. On the other hand, research directly addressing children's conceptions of distance and length, most notably Piaget's work, suggests exactly the opposite conclusion.

Piaget pointed out that the concept of distance is fundamental to mature notions of space. Distance involves fixed intervals of space, and in Piaget's view a conception of distance "provides the necessary conditions for the emergence of space as a common medium out of primitive topological intuitions" (Piaget, Inhelder & Szeminska, 1960, p. 70).

According to Piaget, young children have a profoundly different conception of distance than do adults. In fact, strictly speaking, they do not have a conception of distance since they do not conceive of distances as fixed units of space. As a result, they cannot conceive of space itself as a three dimensional medium, or a framework of fixed extent that remains unchanged as objects change positions within it. Instead, according to Piaget, "the perceptual and intuitive universe of young children is subject to constant deformation and is thus much closer to the elastic and contractile space of topology than it is to the invariants of Euclidean space" (Piaget, et al., 1960, p. 90). This is a central theme in a number of Piaget's major works (Piaget, 1946; Piaget & Inhelder, 1956; Piaget et al., 1960) spanning about 15 years of his writing. Young children's lack of a conception of distance is the common theme underlying a variety of manifestations of their spatial shortcomings, including problems in conserving length, constructing maps, measuring objects, judging speed, and representing paths of movement.

The spatial relations which young children do use, according to Piaget, are relations of adjacency and proximity. These allow the child to make certain accurate spatial judgments, for example, to judge which of two objects is farther away from a certain point. Sole use of these relations, however, leads to predictable errors in two other important cases.

First, if shown two routes, lengths, or paths of movement such as in Slide 1 that begin and end at the same points,

children would judge only the proximity of the endpoint to the startpoint in each route, and since they are the same the child should say the routes were equal. Without a concept of distance, which specifies that movement in any direction uses up an interval of empty space, then in Piaget's words, "detours made enroute matter little" (Piaget, 1946, p. 69). In fact, according to Piaget, 84% of children aged 4 1/2 and younger judge such routes to be the same length (Piaget, et al, 1960, p. 92).

A second implication of using adjacency and proximity relations rather than distance relations is that the relation between points A and C will be changed if a third item, B, is placed between them. Consider the arrays in Slide 2. According to Piaget, when young children judge, in the top array, that A and C are near or far apart, it is only in terms of their adjacency to one another. Thus when another item is interposed, in the second array, the adjacencies change. Younger children do not conceive that A and C still have a distance relation between them when B is interposed. Instead, they conceive of two proximity relations, AB, and BC, which cannot be combined into an interval of distance because B is in the way. Younger children thus will tend to judge that A and C are closer when B is added. They do so either because it is now only half as far--that is, they judge only AB or BC not AC--or because both A and C are now near B.

In general then, the use of adjacency and proximity relations, according to Piaget, does not allow young children to coordinate objects within a common, metric spatial structure,

and in particular does not allow an understanding of distance relations. This is one side of the contradiction with which we were concerned. The other side comes from our findings concerning children's ability to plan their search routes so as to take a short rather than a long path between a number of locations (Fabricius, Wellman, & Sophian, in preparation; Wellman, Fabricius & Sophian, 1985). For example, one of the arrays we used is shown in Slide 3. The child has to search both locations (A,B) in order to collect an object at each, and then finish by taking both objects to a specified endpoint (E). The arrays were large; the distance between the major points in this array were 20 feet. Children could take the short route (BAE) or the long route (ABE), but in either case the routes end up at the same place. The proportions of children at various ages who searched first at location A, which leads to the short route, and location B, which leads to the long route, are shown in Slide 4. The tendency for 3 1/2-year-olds to plan to take the short route 58% of the time is significant, and the tendency to plan a short route continues to increase with age. A variety of controls insured that successful performance was not just the incidental product of going to the closest or most salient location first, or of learning over trials. These findings strongly suggest that children did not compare distances solely in terms of proximities of start and endpoints. If they had, then they would have had no basis for choosing one route over another since both start and stop in the same places. Instead, children responded to some distance-related features of the arrays.

Spurred by this contradiction, we have conducted several subsequent studies in order to examine young children's conceptions of distance more directly. In the first set of studies we examined children's ability both to recognize that detours increase the distance of a route, and to conserve the distance of a route despite the interposition of a third item between the start and endpoints. In our first study of this sort, we presented 3 1/2-, 4 1/2-, and 5 1/2-year-olds with instances of the three types of large arrays illustrated in Slide 5. The distance of the two routes to the house are 16 versus 24 feet. For each array the child was asked which was the "shortest" (or "fastest") route to the house. Children were pretested on both comparative terms (short/fast), and performance was comparable for the two terms. As you can see, even 3 1/2-year-olds did well on the rope and lake arrays, averaging 74% correct. To assure ourselves that children were not simply pointing directly to the house and thereby incidentally indicating the shortest route, we tested children in a subsequent study where they had to indicate the "long" route, and obtained comparable results. Thus even 3 1/2-year-olds had some understanding that the route with the detour was longer, in spite of the fact that both routes begin and end at the same points. At the same time, however, performance was comparatively worse for all ages in the landmark array.

In the landmark array, a distinct object (e.g., a tree) indicates the detour route. This could encourage children to misjudge distance in ways described by Piaget. Specifically,

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the detour could be judged shorter because it's composed of 2 proximities which are each shorter than the direct route. Children might compare the first segment of the detour route to the direct route--the distance to the tree with the distance to the house--and conclude that the detour route was shorter. Or, they might compare the last segment of the detour route to the direct route and again conclude that the detour route was shorter. By employing several landmark arrays we systematically tested these influences on children's distance judgments.

The Landmark arrays we used in the first study are shown in Slide 6. Array 1 is the standard Landmark array you saw in the previous slide. In Arrays 2-5, both the detour routes and the straight routes have a landmark situated on them. In Array 2, the two landmarks are equidistant from the starting point, and so comparing only the first segments of the two routes would give no basis for choosing between them. Comparing the last segments, however, would lead to a choice of the straight route as the shorter route. In Array 3, the opposite is true since the landmarks are equidistant from the endpoint. Arrays 4 and 5 are conflict arrays. In each, one route would be indicated by comparing first segments, while the opposite route would be indicated by comparing last segments.

These arrays allowed us to test the fit of a model that specified that children's performance was determined by distance relations, proximity relations or both. The model included three parameters: comparing the routes on the basis of their true distances, comparing only first segments, and comparing only last segments. To illustrate how these parameters might

combine to predict performance, I will show you the data we obtained on the proportion of correct judgments across all arrays (Slide 7).

As an example of how the model works, consider just the 4 1/2-year-olds' data for a moment. Given our model, the Rope and Lake arrays measure children's distance knowledge in the typical case where the detour "uses up" a greater interval of space than the direct route. Performance in Landmark Array 1 is the joint result of this distance knowledge and tendencies to use proximity relations by judging the detour route on the basis of either of its segments. Given that 4 1/2-year-olds perform at 53%, this suggests the combined weight of judging on the basis of first and last segments is about equal to that of distance knowledge, yielding about 50% performance. If that's the case, then performance should increase in Arrays 2 and 3 where one of the proximity relations is in concert with the direct route and the other is inoperative. Performance does increase to 88% and 91%. In Arrays 4 and 5, the previously inoperative proximity relation now conflicts with the other two approaches, and performance decreases to 47% and 78%.

(Incidentally, I should point out that in this study, there is a large discrepancy between arrays 4 and 5 at each age, and that array 4 also seems unusual since it is the only array that does not show improved performance with age. In a subsequent study we were able to determine why this was the case. Array 4 differs from all the other arrays because the angular displacement between the straight path and the detour is smaller. Thus it was more difficult for children to see the two

routes as different, which is consistent with their basically chance level performance at each age. We excluded array 4 from the model in this study, but when we made the routes more perceptually distinct in subsequent studies, there was no discrepancy in how the model fit array 4 and the other arrays.

We fit the model to the data arranged in a multifactor contingency table by using log linear modeling techniques. Rope, lake, and landmark arrays were all included. Thus, the estimates we obtained for the distance knowledge parameter reflected children's use of distance relations both in rope and lake arrays, where routes were not segmented, and in landmark arrays where they were segmented. It was possible that children would use distance relations only in the rope and the lake arrays and abandon distance in favor of proximity relations in landmark arrays. In that case, the model would provide a poor fit to the data since the model constrained the distance parameter to be the same across arrays. However, the model provided an excellent fit at each age indicating the robustness of children's distance knowledge. Estimates of the weight of the three parameters--distance knowledge, last segments, and first segments--are shown in Slide 8.

At each age the distance parameter was the primary determinant of performance, and its use increased across ages. Thus children's judgments reflected significant use of distance relations. The use of proximity relations involving route segments was a less important influence on performance, though it did contribute significantly to 3 1/2- and 4 1/2-year-olds' performance. The influence of route segments showed no increase

with age, and by 5 1/2 years had ceased to influence performance significantly.

We have labeled the use of first and last segments "perceptual biases", and this reflects the conclusions we wish to draw at this point. Young children do possess an appropriate conception of distance, evidenced by their performance in Landmark Arrays where both of the classic Piagetian errors could have determined their performance: children might have been swayed by the fact that the routes began and ended at the same points, and by the fact that the routes were segmented. Instead, distance relations constituted the primary influence on performance for even 3 1/2-year-olds. At the same time, evidence for the Piagetian errors was not entirely lacking: for example, children did show significant though small tendencies to use proximity relations based on route segments. Rather than indicating a fundamentally different conception of distance, however, these effects are best interpreted as indicating children's inefficiency in combining segments of a route into a representation of the total route. As such, these errors represent perceptual biases that compete with children's basic knowledge of distance, rather than representing fundamentally different conceptions of distance itself. Such biases obscure children's performance, to be sure, which complicates the diagnosis problem. Recall, for example, that in our Landmark Array 1, 3 1/2- and 4 1/2-year-olds were correct only about 50% of the time. Rather than reflecting performance due to chance, however, this reflects equal weight given to distance knowledge and perceptual biases. Our results indicate that it is possible

to distinguish the two and obtain quantitative estimates of each.

These findings and conclusions alone shed considerable light on young children's conception of distance. But there is more to this story. For example, it is possible that Piaget would not find results such as these very troubling. Piaget wished to focus on the child's conceptual construction of space, the child's reasoning and thinking about space. In the type of search and judgment tasks we have discussed so far it is at least possible to suppose that a young child might be able to compute a distance estimate for the paths and compare them (e.g., by visually scanning the paths and comparing the scan times). Such a child might at the same time possess little ability to reason about distance in a more logical or more principled fashion.

In a further study, we have contrasted such perceptual computation of distance and use of more general distance principles. To set the stage for this study, consider the following: If I tell you there are 2 paths that start and stop at the same places--one direct and one indirect--you know that the direct one must be shorter. And you know that without ever having to see the paths. Slide 9 shows this principle, termed the Direct-Indirect principle, and a second principle, termed the Same-Plus principle. Both are distance principles because they allow you to determine the long path even in cases where you can not see the actual paths and thus could not compute actual distances and compare them.

We showed children two paths, a red path and a blue path,

represented by two strips 8 to 16 inches long. Then these paths were covered up. The experimenter told the child what she was going to do to one of the paths under the screen. This is illustrated in Slide 10. For same-plus tasks, she added or subtracted a segment from one of the paths. For example, the child saw her place a red segment under the screen or remove a red segment from under the screen. For direct-indirect tasks the two paths were made of elastic strips and after covering them, one of the paths was invisibly deformed. This either changed it from a direct to an indirect path or vice versa. After these invisible changes were made the child was asked which path was shortest, or whether they were both the same. Since all the transformations were done under the screen and the child never saw the resulting final arrays, computation was precluded and correct judgments were likely to require use of distance principles relevant to those transformations.

As a control, we included some distance-irrelevant transformations, e.g., a piece of colored tape was peeled off the middle of one path. Children in both our age groups clearly recognized such changes as irrelevant to distance. Thus, Slide 11 shows how likely children were to apply the two principles to the distant-relevant transformations. Chance is 33% since the child could say the red was shorter, the blue was shorter, or that they both were the same. Even the young children are significantly more correct than chance.

There is more that can be said about the data from this experiment, but this finding alone provides a plausible, if not definitive, demonstration for the claim that preschool children

understand at least two distance rules. That is, even in circumstances where it would be difficult to compute viewed distances directly, young children show an impressive knowledge of distance in that they can still reason logically and conceptually on the basis of two very powerful distance rules. These data argue specifically against the picture of the child as honoring only the "elastic and contractile space of topology", since young children know that the expansions and contractions we used indeed changed distance.

Children's understanding of both the same-plus and direct-indirect principles suggests that when they make errors on direct-indirect problems--as on our rope and lake arrays and as on Piaget's tasks--those errors may simply represent their application of the same-plus principle to a case where the direct-indirect principle is appropriate instead. In other words, Piaget believed such errors revealed lack of a conception of distance. We suggest instead that such errors are due to an inappropriate application of a correct distance principle. We are currently investigating children's use of distance principles across a number of different arrays where same-plus and direct-indirect principles are differentially appropriate. Our results so far indicate that children do consistently apply same-plus principles even when they fail to apply direct-indirect principles. In addition, their justifications for erroneous judgments in direct-indirect arrays often refer to the fact that there is no extra amount on one path extending beyond the endpoint of the other path, an implicit reference to the same-plus principle. Thus, while young children have

formulated fundamentally correct distance principles, they may still have not completely coordinated the application of these principles. In particular, they appear to over apply same-plus reasoning where direct-indirect considerations should come into play.

In summary, across all these studies we claim to have shown that in tasks requiring distance judgments of large-scale paths and of small-scale ones, judgments of paths with and without interposed points, and judgments of visible and unseen paths, that in all these instances, young children's concepts and judgments of space are determined to a significant, though not exclusive degree by a fundamentally correct conception of distance. In all this we agree with Piaget that a conception of distance is basic for an understanding of space, and that it occupies a fundamental position in the child's thinking and reasoning about space. We disagree with Piaget, however, in that we claim that this fundamental acquisition is evident quite early in development.

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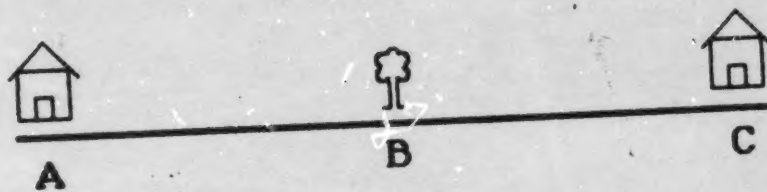
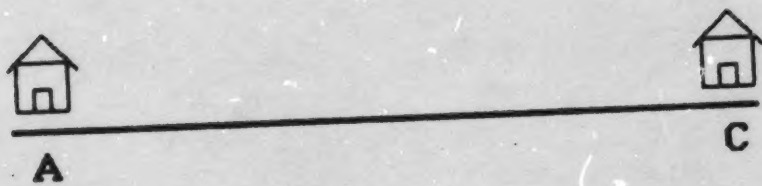
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**Start**

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**Slide 1**



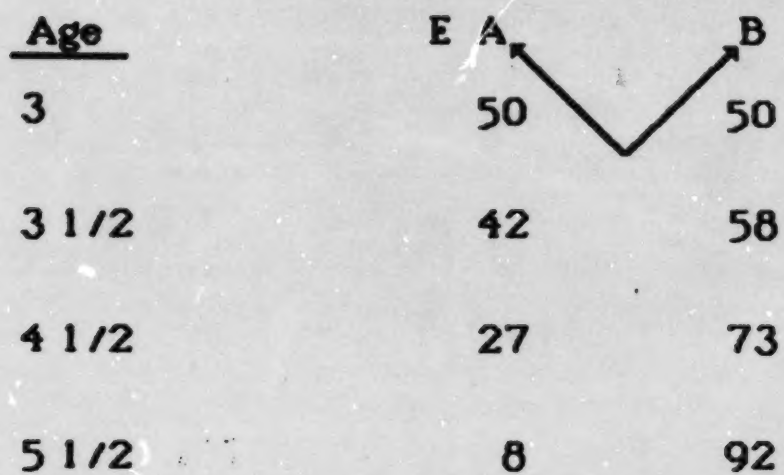
**E A**

**B**

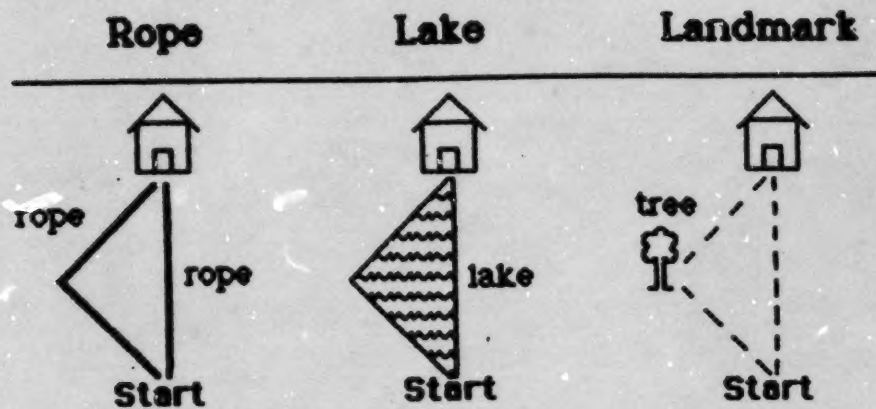
**Start Point**

**Slide 3**

Percentage of First Choices



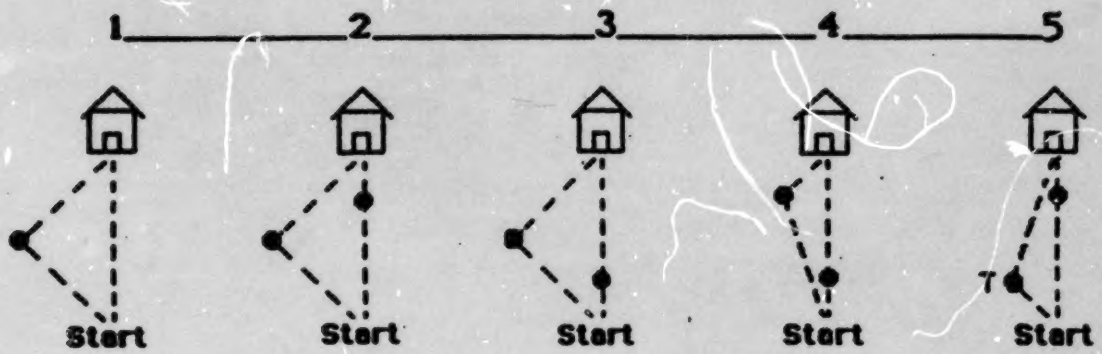
## Array Types



| Ages  | Proportion Correct |     |     |
|-------|--------------------|-----|-----|
| 3 1/2 | .75                | .74 | .47 |
| 4 1/2 | .99                | .83 | .53 |
| 5 1/2 | .99                | .99 | .81 |

Slide 5

# Landmark Arrays



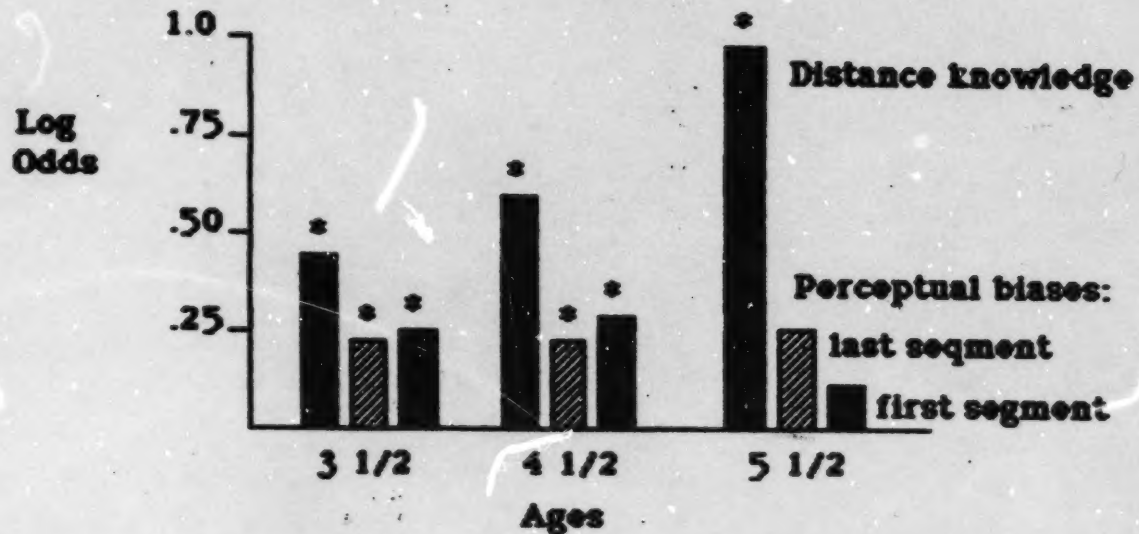
Slide ↩

| Ages  | Landmark |      |     |     |     |     |     |
|-------|----------|------|-----|-----|-----|-----|-----|
|       | Rope     | Lake | 1   | 2   | 3   | 4   | 5   |
| 3 1/2 | .75      | .74  | .47 | .78 | .88 | .59 | .78 |
| 4 1/2 | .99      | .83  | .53 | .88 | .91 | .47 | .78 |
| 5 1/2 | .99      | .99  | .81 | .97 | .94 | .59 | .94 |

Slide 7

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# Parameter Estimates



\* =  $p < .05$

Slide 8

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## Two Distance Principles

Consider two paths A and B that are aligned;  
i.e., their starting and stopping points lie along  
the same linear direction.

### Example

Same-plus Principle: If B is identical to A,  
but then extends a bit further, B is longer  
than A.



Direct-indirect Principle: If A and B go  
between the same points but A goes  
directly and B indirectly, B is longer  
than A.

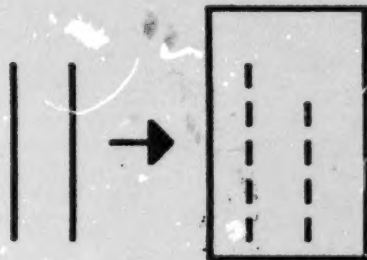


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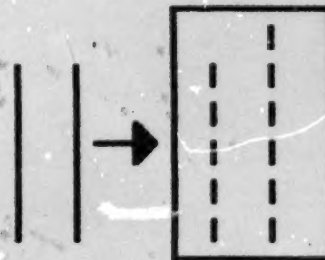
## **Presentations for Distance Principle Tasks**

### **Same-plus Principle:**

**(piece subtracted invisibly)**

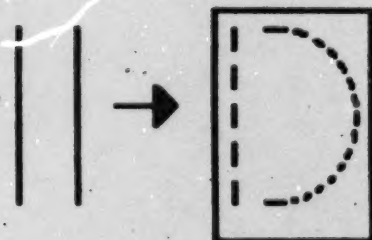


**(piece added invisibly)**

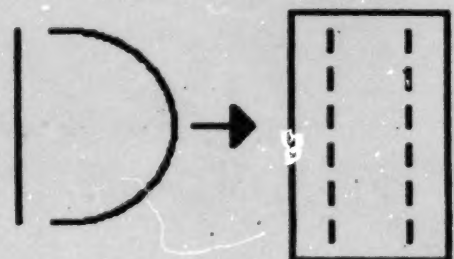


### **Direct-indirect Principle:**

**(piece stretched invisibly)**



**(piece released invisibly)**



## Percentage of Correct Judgments

|                    | <u>Same-plus</u> | <u>Direct-indirect</u> |
|--------------------|------------------|------------------------|
| Young<br>(3.0-4.5) | 56%              | 56%                    |
| Old<br>(4.6-5.11)  | 94%              | 84%                    |